To Process or Not to Process: The Production Transformation Option

by

George Dotsis* and Nikolaos T. Milonas**

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* Department of Economics, National and Kapodistrian University of Athens, 1 Sofokleous street, Athens 105 59 Greece, Tel. +30210 368 3973, e-mail: gdotsis@econ.uoa.gr

** Department of Economics, National and Kapodistrian University of Athens, 1 Sofokleous street, Athens 105 59 Greece, Tel. +30210 368 9442, e-mail: nmilonas@econ.uoa.gr

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Abstract

This paper examines the implications of the production transformation asymmetry on prices of the commodity relative to the prices of its derivative products. When the production transformation process of a harvested good is irreversible, the price linkage between the harvested good and its derivatives breaks. This happens in the case where the supply of the good declines significantly and when independent demand for the good exists. Because the price of the good can rise above the combined value of its derivatives, it is associated with a valuable option not to process. The equilibrium processing margins are derived within a three period model. We show that the option not to process is valuable and can only be exercised by those who carry the commodity. Furthermore, it is shown that a partial hedging strategy is sufficient to reduce all price risk and it is superior to a strategy of no hedging. Preliminary results from the soybean complex support our predictions.

JEL Classification - G13
Kewords: Production transformation, irreversibility, crush margin, soybean complex, hedging

1. INTRODUCTION

One important element akin to most commodity transformations is that such production processes are irreversible, i.e., once processed, the original commodity cannot be reproduced from its derivative products.[1] In the absence of a need to establish reversibility, this production transformation asymmetry would pose no additional complexities. However, if there is independent demand for the original commodity other than that which cannot be accommodated with existent supplies, the inability to "re-create" the commodity from its derivatives will impose certain pricing relationships on spot and futures prices of the commodity and its products.

This paper examines the implications of the production transformation asymmetry on prices of the commodity relative to the prices of its derivative products. It also investigates the behavior of processing firms as influenced by their desire to survive and profit, and the existence of physical irreversibility.

Various authors have identified the valuable option involved in physically irreversible processes. Because of the flexibility to *commit funds and invest* (Majd and Pindyck(1987)) and to liquidate a *cash position* (Hirshleifer (1972), Milonas and Thomadakis (1997a) and (1997b)) whenever the payoff from such a decision is maximized, the value of the most flexible position would be higher than the value of the less flexible position. The difference in values constitutes the *value of the option*. In this paper we go beyond the issues discussed in these studies to identify the option involved in the asymmetry of production transformations. Furthermore, we present empirical evidence of its magnitude and economic importance.

An intuitive explanation of the value that is attached to the unprocessed commodity is that its holders *can control* the rate of production transformation. One dimension that can be controlled is the quantity to be processed. If there is a need for a commodity to be used in its original form, then processors will have a tendency to reduce the amount of the good that is processed and instead prefer to store it in its original form. This quantity dimension also relates to another controlling element, namely the timing of transformation, a firm decision. Both quantity and timing can be used as "antidotes" to the existence of production asymmetry and help achieve maximum benefits.

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[1] The term "irreversibility" used here is consistent with Georgescu-Roegen's (1971) definition: "...all processes which though not reversible, can return to any previously attained phase."

As an example to the problem we present here consider the case of the soybean complex. Soybeans are typically crushed into soymeal and soyoil, but also enjoy demand for consumption in their original form.[2] The natural dependence of soymeal and soyoil to soybeans introduces a strong price interrelationship among the three commodities. Factors affecting the demand for and supply of each commodity in each market (e.g., grains, edible oils, animal feeds) influence the price not only of that commodity but also of the other two. In addition, certain factors related to the nature of the soybean crushing process and the commodities involved may systematically affect the observed price relationships. Such systematic influences may weaken the price interdependence expected in the soybean complex and thus erroneously suggest the existence of market inefficiencies. One such element surrounding the crushing process is the unidirectional process of transformation of soybeans into soymeal and soyoil. This physical asymmetry is empirically tested with soybean complex prices.

Section II presents the concept of physical irreversibility in a crushing process as discussed in the literature and Section III develops the model. Section IV describes the economics of soybean crushing while the testable hypotheses, data and methodology used are outlined in Section V. The empirical results are presented in Section VI.

II. The Irreversibility of the Crushing Process

The possibility of "transforming" a commodity into its derivatives suggests that any sudden increases in the price of derivatives relative to the commodity can be met quickly with additional processing. However, because “reverse processing" is not possible, there is no similar equilibrating mechanism from the processed product side in the case the commodity is priced higher than its derivatives. The lack of such a mechanism will render a price advantage for the commodity relative to its derivatives. This price advantage is due to the flexibility enjoyed by the holders of the commodity to initiate processing at an optimal time and in the optimal quantity so that the benefits are maximized. Under perfect market conditions the magnitude of the commodity price advantage is expected to be market determined and based upon the potential value of the benefits.

This price advantage resembles an *option not to process* in which commodity holders are rewarded with a payoff whenever the prices of the commodity have risen above the equivalent value of its derivatives. This option could be offset only if it was technically possible to make the

[2] Soybeans can also be processed to yield soymilk, soy flour, tofu, etc.

commodity from its derivatives. The inherent inability to imitate nature, however, results in an advantageous pricing of soybeans relative to its derivatives.

Various authors have identified the valuable option involved in physically irreversible processes. Hirshleifer (1972) has examined the inability to revise consumption and investment plans in the presence of new information. This loss of flexibility is greater, the further away a contract (or investment) is from maturity, and vice versa. Short-term contracts (assets), therefore, are priced higher, ceteris paribus, relatively to long-term products.

Baldwin and Meyer (1979) developed a sequential decision process model to deal with irreversible investments. The inability to reverse committed resources associated with irreversible investments generates liquidity premia on prices of short-run (and more flexible) investments over long run (and less flexible) investments. On the same subject, Majd and Pindyck (1987) have examined the effect of the option to postpone an irreversible investment expenditure on the investment decision. They found that the option value is not trivial and it is at its greatest magnitude when, among other things, the uncertainty is greatest.

In another paper Grauer and Litzenberger (1979) explicitly incorporate the problem of physical irreversibility in agricultural commodities. In their model, the "unfeasibility" of transporting the commodity backwards in time puts in effect necessary arbitrage conditions which affect the constellation of futures prices and the spot-futures price relationship.

Recently Milonas and Thomadakis (1997a, 1997b) have analyzed the convenience yield in commodity markets. The authors argue that the existence of stored inventories acts to absorb demand fluctuations in periods between production times. In this way stored inventories offer the option to either liquidate or continue to store, depending upon the relative pricing between spot and futures. Since it is possible that spot prices may rise above futures prices during the storage period, there is a positive payoff when selling spot and buying futures. Therefore, the option to liquidate inventories is essentially the convenience yield and has a positive value. The empirical results on corn, wheat, and soybeans give support to these arguments.

This research on irreversible processes justifies the existence of a premium for commodities and contracts that can potentially reach higher values. In the case of the soybean complex, since owing soybeans allows millers to either crush or continue to store, the option not to crush will have a non-trivial value. This value may be thought as being independent of the convenience yield associated with either soybeans or that of soymeal and soyoil.

The option not to crush may also have value because of the transportation cost differential between the commodity and its derivatives. In the case of the soybean complex because the cost of transporting soybeans is lower than the cost of transporting its derivatives,[3] the possibility of reducing transportation costs is lost once soybeans are crushed. Therefore, exporters or millers will have a preference to store soybeans and refrain from crushing. In this way they essentially are prolonging the option expiration and thus enhancing its value.[4]

Below we present a general model for pricing the processing margin of a harvested commodity that can be decomposed to n different products.

III. THE MODEL

We consider a model with one agricultural commodity and three non-consecutive dates (0,1,2). Day 0 corresponds to the beginning and Day 2 to the end of the production cycle. Day 1 is an intermediate day within the cycle. The commodity is planted on day 0 and is harvested on day 2. The commodity is stored at time 0 from the previous harvest and is carried in storage within the period. With a known transformation process the commodity can be decomposed into n independent products. The value of the harvested good is mainly an additive function of the value that the derivative products can fetch. However, demand for consuming of the commodity itself is also allowed.

Processing firms are competitive and operate at the point where processing margins cover marginal costs. At each of the three days market conditions reveal the marginal cost of processing one unit of the original good, or the processing margin: PM_t. where t=0,1,2.

We allow for demand uncertainty in both days 1 and 2 which correspondingly affects the spot trading prices of the original commodity, $P_{c,t}$ and its products $P_{i,t}$ (where i=1....n and t=1,2). Besides spot trading, futures markets exist and help processing firms control for price uncertainty in the harvested good and its products. In fact, it is assumed that at time 0 processing firms follow the following two strategies:

(1) *Choose not to hedge:* Buy and sell only in the spot market at time 1.

[3] See Houck et. al (1972)

[4] Paul (1966) suggested that soybean millers take speculative positions in soybeans in an effort to stay in business and offset the unfavorable crushing margins they face.

(2) *Choose to hedge the price of the n products:* Buy the original good at time 0 and simultaneously sell futures contracts of the n products maturing at time m (where m=1,2) at prices $F_i(0,m)$.

At time 0 we observe spot and futures prices of both the commodity and its n products. We can therefore define the processing margin as follows:

$$PM_0 = \sum_{i=1}^{n} \alpha_i P_{i,0} - P_{c,0} \tag{1}$$

where α_i is the quantity of product i obtained from crushing one unit of the commodity.

Define the cost of storing one unit of the original commodity between two trading dates t and t+1 as $c_c(t,t+l)$, and the cost of storing product i as $c_i(t,t+l)$. Then the relationship between spot and futures prices at any date t in which storage exists for the original commodity and its products will be:

$$P_{c,t}+c_c(t,t+l) = F_c(t,t+l) \tag{2a}$$

$$P_{i,t}+c_i(t,t+l) = F_i(t,t+l) \tag{2b}$$

In the case that equations (2a) and (2b) are violated, arbitrage will enforce the relationships again through processing and adjustments in the storage and/or open interest as long as the original commodity exists.

At time 1 we observe spot and futures prices for the commodity and its products. The *unhedged processing margin* may be different than PM_0 as long as relative prices between the commodity and its product have changed.

$$PM_1^U = \sum_{i=1}^{n} \alpha_i P_{i,1} - P_{c,1} \tag{3}$$

Furthermore, if firms have chosen to follow the second strategy, they will face a *partially hedged processing margin:*

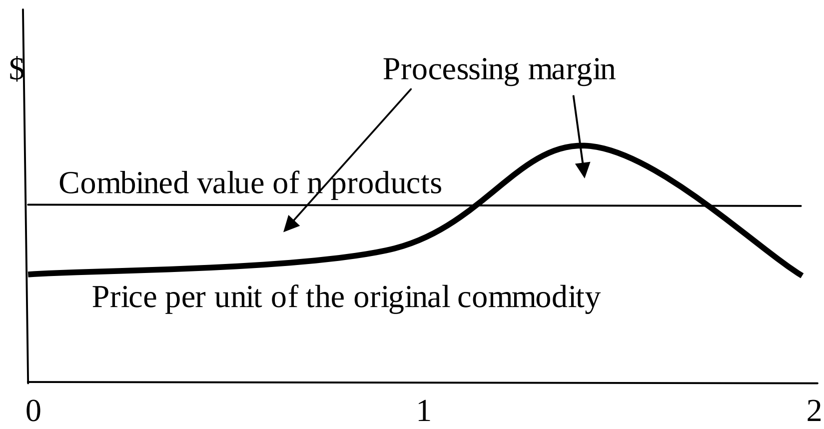
$$PM_1^H = \sum_{i=1}^{n} \alpha_i F_i(0,1) - P_{c,0} - c_c(0,1) \tag{4}$$

Suppose now that there is excess demand for any or all products n so that $PM_1^U > PM_0$. As long as inventories of the harvested commodity exist, processing firms will have the incentive to process. This will put an upward pressure to its price and downward pressure to the prices of its products. The incentive to process will disappear at the point where $PM_1^U \le PM_0$. These offsetting actions will therefore force the equality in processing margins in any two periods in the presence of storage and perfect competition among processors. If at any time during the intermediate day 1, however, inventories of the harvested commodity get exhausted, its price may go even higher than the combined value of its derivatives. This may occur as long as there is demand for the commodity to export, transport, consume or process elsewhere. Such excess demand for the original commodity will result in an inequality:

$$PM_1 < PM_0 \tag{5}$$

Since as time progresses the quantity of the stored commodity depletes continuously, one expects a positive processing margin during the early part of the production cycle with sufficient commodity storage. At a later part of the production cycle and as long as the supply of the commodity is sufficient to meet demand, the processing margin will decrease and may even become negative until new supplies arrive at the end of the production cycle. This likely situation is depicted in Diagram 1 when assuming a flat price regime for the n products.

Diagram 1.
The likely intertemporal behavior of the processing margin



At day 0, when the commodity is abundant and all storage bins are utilized, the margin for immediate processing should reach its equilibrium level. However, processing margins for future periods, as calculated from observed futures prices, should reflect the possibility that the commodity may be priced higher than the combined value of its products. So while the observed processing margin PM_O is expected to be free of incorporating this possibility, processing margin in the intermediate period 1 should account for this possibility that equation (5) can be into effect.

In such a case unhedged processing firms will either be forced to operate at disadvantageous processing margins or halt operations until profitable margins become in effect again.

Let us now examine the processing behavior and potential profitability of the firm under the two strategies in the case where storage for the harvested good at time 1 is zero. If the first strategy of no hedging is followed, millers must transact at prices of period 1. Since at intermediate day 1 storage is zero, inequality (5) becomes in effect, and millers have no incentive to crush so they will shut down. If the firm has followed the second strategy of hedging, it faces the following processing margin calculated in Equation (4):

$$\mathrm{PM}_1^{\mathrm{H}} = \sum_{i=1}^{n} \alpha_i F_i(0,1) - P_{c,0} - c_c(0,1) \tag{4}$$

Because of equation (2b) and for t=1, however, we can write:

$$\mathrm{PM}_1^{\mathrm{H}} = \sum_{i=1}^{n} \alpha_i [P_{i,0} + c_i(0,1)] - [P_{c,0} + c_c(0,1)] =$$

$$= \sum_{i=1}^{n} \alpha_i P_{i,0} - P_{c,0} + \sum_{i=1}^{n} a_i c_i(0,1) - c_c(0,1) \tag{6}$$

Because of equation (1), the last equation can be simplified as follows:

$$\mathrm{PM}_1^{\mathrm{H}} = \mathrm{PM}_0 + \sum_{i=1}^{n} c_i(0,1) - c_c(0,1) \tag{7}$$

From equation (7) it becomes obvious that, despite the fact that commodity storage in the market is zero, millers who choose to process at day 1 realize the normal processing margin of period 0 after paying for net carrying costs. This is a fundamental result of hedging. What is also interesting is that one does not need to hedge all prices. Only the product prices need to be hedged; the original good could be carried from day 0. This is because of the asymmetry that exists between price movements of the products and price movement of the harvested good. While the value of the derivative products is not likely to exceed the value of the original good for a long period, the value of the original good can rise indefinitely above the combined value of the derivatives, as long as extra demand exists.

Processing firms can lock from day 0 the minimum crushing margin calculated in equation (7). The upper bound of the crushing margin is constrained by equation (7) since it depends largely upon the cash price of the commodity, $P_{c,1}$ and the prices of the derivative products, $P_{i,1}$ (i=1,…,n). The relative pricing of the commodity versus its derivatives will affect millers' decision to process or not to process. This will depend upon their yield from such action.

Much like other firms, processing firms depend upon the business of their customers and their ability to serve their needs. Fulfilling customers' needs is a prime concern since this will help them stay in business. Such a valuable priority is known to early researchers (Keynes, Working) as convenience yield. This yield takes value at times when the supply of the commodity is scarce. At all other times it has a small value. Assuming that processing firms value their business most, it is expected that they will continue to process despite the existence of convenience yield.[5]

If millers choose to process, their hedging action will yield:

$$PM_1^H = \sum_{i=1}^{n} \alpha_i F_i(0,1) - P_{c,0} - c_c(0,1) \tag{4}$$

Furthermore, if hedged millers choose not to crush and instead release the original good to the market, they will realize:

$$\sum_{i=1}^{n} \alpha_i F_i(0,1) - \sum_{i=1}^{n} \alpha_i P_{i,0}\ [P_{c,0} + c_c(0,1)] + P_{c,1} \tag{8}$$

By subtracting equation (4) from equation (8) we can find the condition under which millers will choose to process or choose not to process and liquidate:

If $P_{c,1} > \sum_{i=1}^{n} \alpha_i P_{i,1}$, then millers should not process but sell the harvested good to the spot market and realize the payoff g_1: $g_1 = P_{c,1} - \sum_{i=1}^{n} \alpha_i P_{i,1} = -[\sum_{i=1}^{n} \alpha_i P_{i,1} - P_{c,1}] = -PM_1^U > 0$

If $P_{c,1} < \sum_{i=1}^{n} \alpha_i P_{i,1}$, then millers should process and realize PM_1^H. In such a case the value of the payoff is: $g_1 = 0$

[5] A recent example of such behavior is that of the Saudi Arabia declared decision to continue to extract oil (i.e., processing oil fields to turn into crude oil) despite low oil prices in order to maintain its current market share.

This result shows that by not processing, hedged millers can realize an additional benefit equal to the absolute value of the processing margin faced by unhedged millers. It also suggests that when the storage of the original good is reduced to zero, the loss that unhedged millers will incur from processing is the gain to the hedged millers from not processing.[6]

It turns out that the way we have derived payoff g_τ, it resembles a *call option not to crush* written on any storable commodity with a crop cycle which can be decomposed to other products. An important feature in this model is that the original commodity must have independent demand. The possibility that a positive payoff is likely to occur will be incorporated in the price of the commodity. Its value can be calculated using the original Black and Scholes (1973) option pricing model and as a function of five variables:

$$V(\tilde{g}_1) = V(P_{c,1}, X, T, \sigma_{c,1}, r) \tag{9}$$

where:

$P_{c,1}$ is the spot price of the original commodity at time t,

X is the observable exercise price at time t and is equal to: $X = \sum_{i=1}^{n} \alpha_i P_{i,1}$

T is the time until the option matures,

r is the rate of interest,

$\sigma_{c,1}$, is the standard deviation of price changes of the original commodity.

IV. The Economics of Soybean Crushing

As with all production processes, for soybean processing to take place, oil miller must ensure sufficient revenues which adequately reward all factors of production involved. If the processing industry is truly competitive, then soybean processors should only make a normal profit. This profitability can be measured by the Gross Processing Margin (or Crush Margin), the spread in the cost of soybeans and the value of the processed soybean meal and oil. Using equation (1) and crushing yield data we can establish the crushing margin, $PM_{c,t}$, at time t:

$$PM_{c,t} = Q_m P_{m,t} + Q_o P_{o,t} - P_{b,t} \tag{10}$$

[6] As long as neither hedged nor unhedged millers would have any incentive to process, the supplies of the derivative products will begin to decline. This will force their prices higher until processing margins become attractive again and processing resumes.

where:

$PM_{m,t}$ represents the price per pound of the soybean meal,

$P_{o,t}$ is the price per pound of soybean oil,

$P_{b,t}$ is the soybean price per bushel,

Q_m is the number of pounds of meal remaining after 60 pounds (1 bushel) of soybeans are crushed, and

Q_o is the number of pounds of oil extracted from 60 pounds of soybeans.

A positive crush margin that covers the marginal production cost offers the incentive to the oil miller to crush soybeans. In the cases where the crush margin increases substantially (usually at times immediately after the soybean harvest when soybean prices are depressed relatively to soymeal and soyoil prices), the oil mill processors will intensify their crushing. As a result, they buy soybeans and sell soybean oil and meal. Such systematic actions followed by all processors will increase the price of soybeans and decrease the price of the derivative products so that the crushing margin will again fall to more acceptable levels.

In contrast, in the case of scarce supplies of soybeans (before the new harvest and during the summer months), the price of soybeans is higher relative to the prices of the two derivatives so that the crushing margin is at very low levels or even negative. While oil millers do not seem to have any economic incentive to crush soybeans under a disadvantageous crushing margin, they may still find it profitable to operate if they:

(1) have bought bean futures contracts that guarantee delivery at this time and at a price that justifies crushing,

(2) have stored soybeans bought at an earlier time while simultaneously have sold soymeal and soyoil futures.

(3) have placed a cross hedge sometime earlier with an advantageous crushing margin, and

(4) initiate a "reverse hedging" strategy in the futures market.

If the option not to crush were to have any value, it would be in the cases with disadvantageous crush margins. During these cases beans sell at a premium relative to the combined value of its derivatives so that the crushing yield becomes negative. Had bean millers expected a situation like this they may have initiated any one or a combination of the first three strategies. However, in the event they had not, millers may still continue to crush if they engage in strategy (4). However, placing a reverse crush spread in the futures markets does not guarantee an advantageous gross margin. Just as the crush spread proves useful in protecting millers' revenues only when the crush margin in the spot markets decrease, the reverse crush spread will prove beneficial if the crush margin increases.

Speculating on the direction of the crush margin although may prove rewarding, is associated with large risks. Although some speculation on the part of oil millers may not be ruled out, it is assumed that they will choose to hedge most of their production activities through one of the first three strategies. However, earlier in our model we showed that because of the asymmetry of price movements between the oroginal good and its derivatives, the second strategy of buying and carrying soybeans while hedging for the prices of the derivatives is sufficient to guarantee profitable processing margins. Our empirical analysis will therefore examine only this strategy.

V. TESTABLE HYPOTHESES, DATA, AND METHODOLOGY

Within the context of the soybean complex (soybeans, soymeal, soyoil) we can examine empirically two of our main theoretical derivations.

Our first testable hypothesis is whether *hedging is a more preferable strategy than no hedging*. One way to examine this is to compare the processing margins that each of the strategy will yield:

H_O: $PM_1^U = PM_1^H$, i.e., there is no difference in the effectiveness of the two strategies.

H_1: $PM_1^U < PM_1^H$, i.e., the hedging strategy is superior to the strategy of not hedging.

At a preliminary stage of empirical testing, end of month spot and futures prices were collected from the Wall Street Journal for the three commodities. All futures prices were converted to 1966 prices using a producer price index based on grains. For each futures contract we also collected the yield of a Treasury bill with matching maturity. Since the harvest of soybeans is completed by the end of fall, we designated the month of December as the month in which the two strategies are initiated. During this time soybeans are abundant and the crushing margin is likely to be positive and advantageous. The crushing margin, however, is likely to fall at a later time when soybean domestic supplies are reduced while foreign crops (i.e., Brazilian, Argentinean) have not been harvested yet to offer relief. This later time is towards the end of spring or the month of May. The effectiveness of the two strategies is, therefore, compared at the end of April relatively to the prices in December.[7] We assume that millers do not change their strategies once placed in December. This assumption basically affects the hedging strategy.

In calculating PM_1^U from equation (3) or its analog equation (10), we use bean, meal, and oil spot prices of the respective May futures contracts observed on the last trading day of April. Meal and oil crushing yield data were calculated from the Bureau of the Census Current Industrial Reports monthly publication (various issues) entitled "Fats and Oil-Oilseed Crushing." The calculation of PM_1^H was based on equation (4). The spot price of the January soybean futures contract observed on the last trading day of December was continuously compounded until the last trading day of April using the matching Treasury bill yield observed also at the end of December. This procedure adjusts for the carrying charges between December-April incurred by the miller when storing soybeans.[8] The prices of the May soymeal and soyoil futures contracts observed at the end of December were also obtained to calculate PM_1^H.

After calculating PM_1^U and PM_1^H we can calculate their difference and test whether it is significantly different from zero. Furthermore, we can estimate the value of the payoff g_τ. In doing so we assume that a rational miller will not crush as long as the negative value of PM_1^U is greater than PM_1^H. In such case the payoff will be simply: $-PM_1^U$. In all other cases millers were expect to crush and realize: PM_1^H.

The second testable hypothesis which we will examine is whether *the payoff g_τ of equation (9) resembles an option on the spot price of the harvested commodity*. In light of this hypothesis we will test the applicability of an option valuation model with stochastic exercise price to the payoff from not crushing, i.e., $-PM_1^U$, the negative of the unhedged margin in period τ.

VI. EMPIRICAL RESULTS

Table 1 presents the two crushing margins for the 11-year period observed at the end of April, their difference as well as the payoff g. The average, standard deviation and the statistics are also shown. The average of both crushing margins is positive although in certain years it becomes negative. Although the hedging strategy yields an average 4.23 cents superior crushing margin

[7] In other words, April is the intermediate day 1 in our model.
[8] Brennan (1991) used this procedure to calculate carrying charges.

over the no-hedging strategy, the difference lacks statistical significance. Nevertheless, as it turns out, the correct comparison is not between the two crushing margins but between the unhedged crushing margin PM_1^U and the total benefit that will result not only from *hedging and crushing* but also from *hedging, not crushing and selling*.

This is shown in the last column of the table and is the PM_1^H when crushing takes place and the payoff g_1 that occurs when crushing does not take place. Over the 11-year period, there were three years (1975, 1977, and 1978) when the option not to crush should have been exercised. This coupled with the remaining years of crushing yielded an average 10.77 cents effective crushing margin per bushel of soybeans crushed when millers chose to hedge. Although the small number of observations cannot provide statistical significance to the 8.37 cents difference in the two strategies, the present evidence suggests the importance of hedging in helping millers determine optimal production policies.

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TABLE 1

Comparing the Effectiveness of the Hedging and the No Hedging Strategies and the Payoff from Not Processing

Date	PM_1^U	PM_1^H	PMDif	g_1	Total Benefit
730430	18.20	-2.03	-20.23	0.00	-2.03
740430	20.00	-13.18	-33.17	0.00	-13.18
750430	-1.41	-4.16	-2.75	1.41	1.41
760430	5.47	6.64	1.17	0.00	6.64
770429	-13.39	.05	13.44	13.39	13.39
780428	-26.56	-.19	26.38	26.56	26.56
790430	7.27	4.75	-2.52	0.00	4.75
800430	-.58	34.57	35.16	0.00	34.57
810430	13.33	32.41	19.08	0.00	32.41
820430	-.01	7.82	7.83	0.00	7.82
830429	4.07	6.17	2.11	0.00	6.17
Average	2.40	6.62	4.23		10.77
Standard Deviation	13.53	14.57	19.67		14.83
t-statistics	0.59	1.51	0.71		2.41[a]

[a] significant at the 1% level.

PMDif= PM_1^H - PM_1^U

Total Benefit = PM_1^H (when crushing takes place) + g_1